U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-298 545

Atmospheric Stability Class Determinations on a 481-Meter Tower in Oklahoma

(U.S.) Environmental Sciences Research Lab,
Research Triangle Park, NC

23 Jan 78

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3.
EPA-600/J-78-118	JOURNAL ARTICLE	PB 298545

4. TITLE AND SUBTITLE	5. REPORT DATE
ATMOSPHERIC STABILITY CLASS DETERMINATIONS ON A 481-METER TOWER IN OKLAHOMA	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Gerard A. DeMarrais	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
(Same as Block 12)	1AA603 AD-05 (FY-77)
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

REFERENCE: Atmos. Environ., 12(10):1958-1964, 1978.

16. ABSTRACT

Data from seven heights on a 481-meter tower in Oklahoma are analyzed to show the variation of stability with height and time. Wind direction fluctuations at the various heights are analyzed to determine the stability class associated with horizontal dispersion and the temperature difference between pairs of heights are analyzed to determine the class associated with vertical dispersion. The Oklahoma results are compared to previously reported results obtained on a 367-meter tower in South Carolina. The results from the two widely separated sites corroborate one another. The two classifying techniques at both sites show that there is a marked increase in stability a little above 100 meters. This result indicates that dispersion estimates for effluents from stacks taller than 100 meters could readily be in error when based on observations below 100 meters; the observations at the lower heights would indicate more rapid dispersion than would be indicated at effluent height.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Meteorology Determination *Stability Towers		04B 13M

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	10
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	A02-A01

EPA Form 2220-1 (9-73)

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Atmospheric Environment Vol. 12, pp. 1957–1964.
Pergamon Press Ltd. 1978. Printed in Great Britain.

0004–6981/78/1001–1957 $02.00/0
EPA-600/J-78-118
JOURNAL ARTICLE

ATMOSPHERIC STABILITY CLASS DETERMINATIONS ON A 481-METER TOWER IN OKLAHOMA

GERARD A. DEMARRAIS*
Meteorology and Assessment Division, ESRL, Environmental Protection Agency, Research Triangle Park, NC 27711, U.S.A.

(*First received* 12 *September* 1977 *and in final form* 23 *January* 1978)

Abstract – Data from seven heights on a 481-m tower in Oklahoma are analyzed to show the variation of stability with height and time. Wind direction fluctuations at the various heights are analyzed to determine the stability class associated with horizontal dispersion and the temperature difference between pairs of heights are analyzed to determine the class associated with vertical dispersion. The Oklahoma results are compared to previously reported results obtained on a 367-m tower in South Carolina. The results from the two widely separated sites corroborate one another. The two classifying techniques at both sites show that there is a marked increase in stability a little above 100 m. This result indicates that dispersion estimates for effluents from stacks taller than 100 m could readily be in error when based on observations below 100 m; the observations at the lower heights would indicate more rapid dispersion than would be indicated at effluent height.

1. INTRODUCTION

The tall stack is often presented as a means for reducing ground-level concentrations of a pollutant (Frankenberg, 1968; Martin and Barber, 1973; Smith and Frankenberg, 1975). The reasoning is that the higher the release the greater the volume available for dilution before the pollutant reaches the ground; a higher release is assumed to mean a greater travel distance and greater spreading in the horizontal and vertical. A recent comprehensive review (Hales, 1976) of the literature referenced many reports on ground level measurements of pollutants emitted from tall stacks but showed that very little information was available on the meteorological conditions associated with the dispersion aloft. The meteorological conditions that frequently have been related to dispersion for heights up to 100 m are wind direction fluctuations (Pasquill, 1961) and thermal stability (Slade, 1968). Statistics on these phenomena for levels above 100 m are presented and the probable meaning of these results with regard to dispersion are discussed.

The statistics come from wind and temperature data gathered at 7 levels on a 481-m tower in Oklahoma City, and emphasis is given to the variation of stability with height and time. Previously reported results for a South Carolina site (Pendergast and Crawford, 1974) are compared to the Oklahoma City findings.

2. BACKGROUND AND METHODS

2.1. *Estimating stability*

Simple techniques for estimating the dispersion of a pollutant in the atmosphere are a century old (Smith, 1859). Generally, a means of measuring or estimating the horizontal and vertical spread by air movement or the wind is used. Pasquill (1961) presented curves for estimating dispersion during six different stability conditions when direct measurements were not available. The estimates were based on wind speed, insolation, time of day, and cloudiness. The class-based conditions ranged from *A*, most unstable, through *D*, neutral, to *F*, most stable. The estimating technique was modified by Gifford (1961) and by Turner (1970), and Bryant (1964) added a seventh class, *G*, but the classifications are still referred to as Pasquill stability classes. Pasquill (1961) did recommend fluctuations should be used when available; however, measuring these parameters is usually a difficult and time-consuming or expensive task. Another frequently employed technique is to measure the temperature difference between two heights and relate this difference to stability classes (Slade, 1968). The Nuclear Regulatory Commission (NRC) (1972) developed guidelines by which either the standard deviation of wind direction, σ_{WD}, or the temperature difference, $\Delta T/\Delta Z$, may be related to a Pasquill stability class. The relationships are shown in Table 1; each stability class in progressing from *A* to *G* means less spreading. Although not stated, it is generally preferred that the class of horizontal spreading be determined by wind direction fluctuations and the vertical spreading by temperature differences. Statistics on stability class distributions based on these guidelines, are used to demonstrate how stability conditions change with height and time.

2.2 *Related findings*

On the basis of observations of temperatures on a

*On assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Table 1. Classification of atmospheric stability, according to NRC Safety Guide 23 (see Nuclear Regulatory Commission reference)

Stability classification	Pasquill categories	$\sigma_{\theta_D}^*$ degrees	ΔT temperature change with height °C 100 m^{-1}
Extremely unstable	*A*	25.0	< -1.9
Moderately unstable	*B*	20.0	-1.9 to -1.7
Slightly unstable	*C*	15.0	-1.7 to -1.5
Neutral	*D*	10.0	-1.5 to -0.5
Slightly stable	*E*	5.0	-0.5 to 1.5
Moderately stable	*F*	2.5	1.5 to 4.0
Extremely stable	*G*	1.7	>4.0

* Standard deviation of horizontal wind direction fluctuation over a period of 15 min–1 h. The values shown are averages for each stability classification.

187-m tower near Tilbury, England, Moore (1967) concluded that the environment was usually stable above 150 m if thermals were disregarded. Slade (1969), summarizing data from a 270-m tower in Philadelphia, showed that on the average, in the afternoon, the layer between 175 and 270 m was stable while below, the layers were unstable. Using wind observations at heights of 30 and 120 m, Slade (1968) showed that the fluctuations in wind direction decreased with height, but did not indicate whether there was a limit on this decrease.

The first detailed report (Pendergast and Crawford, 1974) on the variation of classes with height up to several hundred meters was recently presented. A 367-m tower near the rural community of Beach Island, South Carolina, was the source of the data. This site, the Savannah River Plant (hereafter called Savannah River), is 11 km southeast of Augusta, Georgia. The terrain in the immediate area is rolling, and there are pine forests (trees about 11 m tall), pastures and fields. Stability classes were determined according to the NRC guidelines shown in Table 1. One-hour sampling periods were used for 22 June to 23 November, 1973; there were 3600 sampling periods. The standard deviations of wind directions, σ_{WD}, were employed to determine the relative frequency of stability classes for seven levels from 10 to 304 m. The results are shown in Table 2. These results will be discussed, along with the Oklahoma findings in the paragraphs which follow. The relevant $\Delta T/\Delta Z$ analyses in the report (Pendergast and Crawford, 1974) were for five layers, some of which overlapped. The results of these analyses are shown in Table 3.

2.3 *Oklahoma City tower data*

The data analysed in this report were gathered on the WKY-TV tower, located 10 km north-northeast of downtown Oklahoma City, Oklahoma, in gently rolling terrain, which varies less than 40 m in elevation within a 4-km radius of the tower. The TV transmitter building is the only nearby structure; 12 m high, it is 65 m west-southwest of the tower.

The National Severe Storms Laboratory installed meteorological equipment on the tower in 1966. Instruments for measuring horizontal wind and temperature are mounted at 26, 44, 89, 177, 266, 355, and 444 m on the 481-m tower. The booms on which the instruments are mounted are aligned to an azimuth angle of 240° (the prevailing winds are from the south and southwest). Horizontal wind speed and direction are sensed with Bendix model 120 Aerovanes, which are mounted about 3 m out on the booms. Tempera-

Table 2. Frequency distribution of stability classes based on σ_{WD}, Savannah River Plant, 22 June–23 November, 1973

Height (m) \ Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*
10	23	14	22	29	9	*	3
36	19	12	19	32	16	1	1
91	10	7	13	22	30	16	2
137	9	6	12	21	29	18	5
182	7	3	7	17	26	25	15
243	8	4	9	18	28	23	10
304	7	4	8	17	29	24	11

Note: based on one hour sampling periods. Total number of cases equalled 3600
* Less than 0.5%.
σ_{WD} – standard deviation of wind direction

Table 3. Frequency distribution of stability classes determined by $\Delta T/\Delta Z$. Savannah River Plant, 22 June–23 November, 1973

Layer \ Class	A	B	C	D	E	F	G
10–36 m	8	2	2	11	10	31	36
36–91 m	4	4	9	32	35	13	3
91–137 m	16	12	12	33	23	4	*
91–243 m	0	0	0	44	52	4	0
91–335 m	0	0	0	56	44	*	0

* Less than 0.5%

tures are measured with Yellow Springs linearized thermistor composites, housed in aspirated radiation shields that are mounted 2 m out on the booms.

The quality control program and collection of data on magnetic tapes were working so well by the end of 1971 that is was believed that continuous high speed (readings every 10 s) runs could be conducted on days when storms were anticipated in the spring of 1972 (Goff and Zittel, 1974). Although problems were encountered, a good datum set was collected during 400 h between 14 April and 3 July, 1972. Data were collected at all 7 levels and the only missing data were some wind directions at the 26 m level.

2.4 *Analyses of data*

Comparisons of nighttime and daytime data were not included in the Savannah River site analyses, and these comparisons were considered important. Accordingly each day was divided into three 8-h periods, beginning at midnight; this division separated the daytime period (0801–1600), with its thermal instability from the transitional or evening period (1601–2400), and the very stable first or nighttime period (0001–0800). The sampling time was a half-hour. The following were determined for each sampling period for each of the 7 heights: σ_{WD}, based on all 10-s readings; and the average $\Delta T/\Delta Z$ between heights immediately below and above the height for which the σ_{WD} was calculated. In determining the $\Delta T/\Delta Z$ for the 26-m wind-level, the $\int \Delta T$ was between 26 and 44 m, and for the 44 m wind-level, the ΔT was between 355 and 444 m. These derived quantities were converted to stability classes according to Table 1 (classes were separated at midpoint values between classes). In this report the NRC requirements (Nuclear Regulatory Commission, 1972) that the lower measuring instruments be at 10 m and the second set at least 30 m higher are not followed.

The duration of the continuous data collection periods ranged from 4 to 30 h. Some periods included weather during which non-steady state conditions or instrument errors (e.g. aspirated temperature sensors reading wet bulb temperatures in high humidities) could be introduced; half-hour periods with weather that complicated stability class determinations were eliminated. The complicating weather phenomena were: (1) precipitation; (2) fog; (3) clouds below 500 m; (4) wind shifts; and (5) thunderstorms. The records from the National Weather Service Office (NWSO) at Will Rogers World Airport (about 11 km southwest of downtown Oklahoma City) were used to determine when complicating weather occurred. In the final analyses, the following numbers of good-weather half-hours occurred: 231 during 0001–0800; 129 during 0801–1600; and 258 during 1601–2400 (the numbers were lower for the 26-m level because of the missing wind directions). The good-weather days, as shown by the NWSO data, generally had high (above 6 km) or middle (between 2 and 6 km) clouds and moderate (7–12 knots) or strong (> 12 knots) winds. Southeast winds were the most frequent, and southwest winds the least frequent directions, but all directions were observed.

3. RESULTS

3.1 *Stability classes determined by the σ_{WD} technique*

The distribution of the stability classes determined by the σ_{WD} technique is shown in Table 4. This table is comparable to Table 2 except for the breakdown into three 8-h periods. A composite tabulation for 24 hours for Oklahoma City showed the distributions to be similar to those for the Savannah River site. The two non-daytime Oklahoma tabulations show a marked increase in the frequency of stable classes with height below 177 m and, at higher elevations stable classes, *E*, *F*, and *G* predominate. The daytime tabulation shows that neutral and unstable classes predominated; there was an increase in the frequency of *E* stability with height up to 177 m and, above that, the distributions changed slightly with height. The 24-h data at the Savannah River site, shown in Table 2, tend to minimize the high frequency of unstable and neutral classes of the daytime and the high frequency of stable classes at other times. While the daytime Oklahoma stability class distributions are different from those for the evening and nighttime, those for the latter two periods are similar. The frequencies of unstable classes, particularly classes *A* and *B*, were a little higher at the Savannah River site than at the Oklahoma site. The Savannah River site showed a decrease in the frequency of unstable classes with height while only the daytime period in Oklahoma showed a comparable

Table 4. Frequency distribution of stability classes based on σ_{WD}. Oklahoma City, spring–summer, 1972

Height (m) \ Class	A	B	C	D	E	F	G
				0001–0800			
26	5	7	5	49	31	3	
44	6	2	3	32	54	3	
89	2	5	4	16	53	20	
177	4	1	7	13	45	28	2
266	5	3	4	10	39	34	5
355	6	2	4	11	26	48	3
444	4	2	4	6	26	45	13
				0801–1600			
26	8	10	35	44	3		
44	6	8	37	42	7		
89	6	3	26	45	20		
177	4	4	15	42	35		
266	4	4	8	51	33		
355	3	4	10	45	35	3	
444	5	6	8	42	32	6	1
				1601–2400			
26	6	4	7	40	37	2	2
44	8	4	9	34	40	5	
89	6	1	8	18	52	14	1
177	5	3	6	13	43	29	1
266	4	3	5	11	38	34	5
355	4	2	4	11	35	42	2
444	3	1	2	11	32	46	5

σ_{WD} standard deviation of wind direction

Table 5. Frequency distribution of stability classes determined by $\Delta T/\Delta Z$. Oklahoma City, spring–summer, 1972

Layer \ Class	A	B	C	D	E	F	G
				0001–0800			
26–44 m				37	37	18	8
26–89 m				40	37	19	4
44–177 m				38	48	14	*
89–266 m				35	60	5	
177–355 m				33	64	3	
266–444 m				39	60	*	
355–444 m				42	58		
				0801–1600			
26–44 m	29	6	15	46	3	1	1
26–89 m	3	10	18	67	1	1	
44–177 m				96	4		
89–266 m				92	8		
177–355 m				88	12		
266–444 m				79	21		
355–444 m				73	21	6	
				1601–2400			
26–44 m	11		1	29	43	16	
26–89 m	2	3	3	31	46	14	1
44–177 m				53	41	6	
89–266 m				60	40		
177–355 m				71	29		
266–444 m				77	22	*	
355–444 m				66	34		

* Less than 0.5%

result. Previous findings (Slade, 1968) indicated that wind direction fluctuations decreased with height between 30 and 120 m and the results for these two sites indicate that the upper limit is close to 120 m; above that height, as shown in Tables 2 and 4, there was no marked increase in the more stable classes.

3.2 *Stability classes determined by the $\Delta T/\Delta Z$ technique*

The distribution of stability classes determined by the $\Delta T/\Delta Z$ technique is shown in Table 5. Examining both Tables 3 and 5, one sees that classes *D* and *E* predominate in layers with tops above 137 m; unstable classes were not observed in layers above that height at either location. There did appear to be an anomaly in the frequencies of unstable classes at the Savannah River site in that these increased up to the 91- to 137-m layer and then disappeared. At the Oklahoma site the unstable frequencies decreased with height in the day time and evening and were nonexistent above the 26- to 89-m layer. The Oklahoma results showed a progressive increase in the frequency of more stable conditions at each level in going from daytime to evening and then to nighttime. *D* stability was the most frequent in the evening above the 26- to 89-m layer whereas in the nighttime *E* stability prevailed.

3.3 *Co-frequency of stability class*

Table 6 lists the co-frequency of the classes at the Oklahoma site as determined by the two techniques. The total class agreement at the individual heights in the daytime ranged from 33 to 58‰ and during the evening and nighttime it was almost as good up to the 44- to 177-m layer. Above that layer in the two non-daytime periods, however, the σ_{WD} technique indicated more stable cases than the $\Delta T/\Delta Z$ technique. If only one technique were used to provide estimates in the evening or nighttime, the σ_{WD} technique would yield more conservative estimates (less dilution) at the higher elevations. Investigators (The Research Corporation of New England, 1975) examining dispersion

Table 6. Co-frequency of stability classes, Oklahoma City, spring–summer, 1972

		0001–0800 σ_{WD}							0801–1600 σ_{WD}							1601–2400 σ_{WD}						
									Height 26 m													
		A	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
	A								2	3	14	10					1	1	8	1		
	B								1	1		4										
$\Delta T/\Delta Z$	*C*								2	33	6							1				
26–44 m	*D*		2	1	26	8			3	3	14	24	2			1	1	1	16	10		
	E	2	2	3	15	15	•		1		1	1				2	1	2	15	20	1	1
	F	•	2	•	6	7	2					1				3	1	3	1	6	1	1
	G	3	•	•	2	1	•						1									
									Height 44 m													
	A											2	1					•	1			
	B								1		4	5					1	•	1			
	C								1	1	11	4	1			•		•	2			
$\Delta T/\Delta Z$	*D*		•		19	21			4	7	21	31	4			2	•	2	16	11		
26–89 m	*E*	2	1	3	9	22					1					3	1	4	11	25	2	
	F	4	•	•	4	8	2						1			1	1	2	3	4	3	
	G		•	•		3	1									1						
									Height 89 m													
$\Delta T/\Delta Z$	*D*	•	2		11	25			5	3	25	44	18			3	•	5	12	32	1	
44–177 m	*E*	2	3	4	5	23	11		1		1		2			2	1	2	4	19	11	1
	F			•	•	5	9									1			2	1	2	

Table 6 – *continued*

		0001–0800 σ_{WD}							0801–1600 σ_{WD}							1601–2400 σ_{WD}						
Height 177 m																						
		A	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
$\Delta T/\Delta Z$ 89–266 m	*D*	*		2	5	24	4		4	4	14	*41*	29			3	2	4	*8*	30	13	*
	E	4	*	4	8	*19*	22	2			1	1	6			2	1	2	5	*13*	16	1
	F			1	*	2	*2*															
Height 266 m																						
$\Delta T/\Delta Z$ 177–355 m	*D*	2	2	1	*2*	17	7	2	3	4	8	*49*	24			2	2	4	*8*	28	23	4
	E	3	1	3	7	*21*	26	3	1			2	9			2	1	1	3	*10*	11	1
	F				1	1	*1*															
Height 355 m																						
$\Delta T/\Delta Z$ 266–444 m	*D*	5	*	1	*3*	11	17	2	2	3	9	*39*	25	1		3	2	4	*8*	27	31	2
	E	1	1	3	8	*15*	31	1	1	1	1	6	*10*	2		1		*	3	*8*	10	
	F						*														*	
Height 444 m																						
		A	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
$\Delta T/\Delta Z$ 355–444 m	*D*	2	*	1	*1*	12	20	5	3	5	7	*36*	21	1		2	1	3	6	23	26	5
	E	2	2	3	5	*14*	25	7	2	1		6	*8*	4	1	1			5	9	20	
	F										1	1	3	*1*								

* Less than 0.5%
Italics show class agreement

data concluded that use of σ_{WD} for horizontal dispersion and $\Delta T/\Delta Z$ for the vertical spread produces the most accurate results. The poor correspondence in the co-frequency of classes supports the contention that horizontal and vertical dispersion values should be determined separately.

3.4 σ_{WD} *substitute*

It was previously stated that determining the σ_{WD} is usually difficult, time-consuming and expensive. Attempts (Markee, 1963) to simplify the task sought to examine relationships between the extreme range of wind direction and σ_{WD}. The summary of five independent investigations (Markee, 1963) indicated that the directional range, R, divided by 6 (i.e. $R/6$), approximated the value of one standard deviation (when the winds were not meandering). $R/6$ was used to determine stability classes, and co-frequency tabulations similar to those shown in Table 6, were prepared for the three time periods for the seven levels. The total class agreement was approx. 67% at each height and the class distributions were similar for the seven heights. Table 7 shows the results for two heights; the patterns for these heights are typical of those for each of the seven heights. It appears that $R/6$ may be substituted for σ_{WD} in determining stability classes where approximations are sufficient; where greater accuracy is needed the time-saving technique should not be used.

4. SUMMARY AND SIGNIFICANCE

Examination of the previously reported stability data (*not separated to show diurnal variations*) from the Savannah River site and comparable data from the Oklahoma City site has shown specific features which are interpreted as follows:

(1) Stability classes determined by the NRC classification guideline at the two widely separated sites showed similar stability distributions when either the σ_{WD} or $\Delta T/\Delta Z$ technique was used. Since the data from the two sites corroborate one another, the results may be typical of stability aloft at other sites.

Table 7. Co-frequency of stability classes ($R/6$ vs σ_{WD})*

		0001–0800 σ_{WD}							0801–1600 σ_{WD}							1601–2400 σ_{WD}						
Height 44 m																						
		A	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
	A	*4*	+						*4*		1					*3*		1				
	B	+	+						2	*1*	1					2	+	1				
R/6	*C*	2	1	*1*	+					7	*18*					1	2	*3*	*2*			
	D		+	3	*19*	4					17	*35*	1			1		5	*18*	2		
	E				12	*43*						6	7						16	*35*	1	
	G				7	*3*															*3*	
Height 355 m																						
	A	*5*	1	1					*3*	1	1					*4*	+	+				
	B			+					1	*1*						+	*1*	1	1			
	C	1		*1*	+					2	6	2				+	+	*1*				
R/6	*D*		+	2	*4*	2					3	*31*						2	6			
	E			7	*11*								29						4	22	+	
	F				13	*34*							6	3						17	29	
	G					13	*3*														11	*2*

* Italics show class agreement
† Less than 0.5%

(2) Both stability classifying techniques at the two sites indicated that there was a height a little above 100 m where the air became markedly more stable than the air at lower levels. This finding means that dispersion estimates of effluents from stacks taller than 100 m could readily be in error when based on observations below 100 m; the observations at the lower heights would indicate more rapid dispersion than would be indicated by observations at the height of the effluent.

(3) The σ_{WD} technique at both sites showed that stable classes, *E*, *F*, and *G* predominated at all heights above 100 m, but all classes occurred. While on the average the indicated horizontal spreading above 100 m is markedly less than that below, there are times when the spreading may be considerable.

(4) The $\Delta T/\Delta Z$ technique at the two sites showed that classes *D* and *E* predominated in layers with tops above 137 m, and practically no other classes existed in these layers. The indicated vertical spreading in these high layers would seldom show the extremes of either extensive (classes *A* and *B*) or limited (classes *F* and *G*) vertical mixing shown in layers closer to the ground.

(5) Comparison of the two techniques for heights and layers above 100 m shows that the σ_{WD} yields a more conservative estimate of stability class. If only one technique was used to determine the stability class in the horizontal and the vertical, the σ_{WD} method would generally show more stable classes (indicate less dispersion) than the $\Delta T/\Delta Z$ method.

The following are based on the results found at the Oklahoma City site:

(1) According to the σ_{WD} technique, there is a marked increase in the frequency of stable classes in progressing from daytime to evening and in going from evening to nighttime there is a slight increase in the frequencies of more stable layers below 100 m and practically no change above. The inferred horizontal spreading above 100 m is reduced in going from daytime to evening, but there would be little change from evening to nighttime.

(2) According to the $\Delta T/\Delta Z$ technique there is a marked increase in the frequency of stable classes in all layers in progressing from the daytime to evening and from evening to nighttime. The increasing frequency of more stable classes appears to be a continuous process in the two non-daytime periods and vertical spreading would be progressively more inhibited.

(3) Examination for the simultaneous occurrence of classes by the two different techniques showed there was total agreement 32–58% of the time at the individual heights in the daytime and comparable agreement in layers up to 44- and 177-m in the two other periods. But with the higher layers in the non-daytime periods, the σ_{WD} technique generally indicated greater stability than the $\Delta T/\Delta Z$ method. It did not appear that one technique could be substituted for the other in determining stability.

(4) The substitution of the range of direction divided by 6, $R/6$, for the σ_{WD} technique previously used

below 100 m (Markee, 1963), showed that the $R/6$ and σ_{WD} techniques indicated identical classes 67% of the time. Where σ_{WD} is difficult to obtain and an approximation is all that is needed, the simple-to-determine $R/6$ may be substituted for σ_{WD} in determining stability class.

Acknowledgements – Thanks are due to Miss Kathryn C. Gray of the National Severe Storms Laboratory for making available the meteorological data from the Oklahoma City tower. Thanks are also due to Mr. Dale Coventry for his assistance in the analyses.

REFERENCES

Bryant P. M. (1964) Methods of estimation of the dispersion of windborne materials and data to assist in their application. United Kingdom Atomic Energy Authority, Harwell, England.

Frankenberg T. T. (1968) High stacks for the diffusion of sulfur dioxide and other gases emitted by electric power plants. *Am. ind. Hyg. Ass. J.* **29**, 181–185.

Gifford F. A. (1961) Uses of routine meteorological observation for estimating atmospheric dispersion. *Nucl. Saf.* **2**, 47–51.

Goff R. C. and Zittel W. D. (1974) The NSSL/WKY-TV Tower data collection program: April–July 1972. National Severe Storms Laboratory, Norman, OK, 45 pp.

Hales J. M. (1976) Tall stacks and the atmospheric environment. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

Markee E. H. Jr. (1963) On the relationships of range to standard deviation of wind fluctuations. *Mon. Weath. Rev.* **91**, 83–87.

Martin A. and Barber F. R. (1973) Further measurements around modern power stations. *Atmospheric Environment* **7**, 17–37.

Moore D. J. (1967) Concentration measurements near Tilbury power station. *Atmospheric Environment* **1**, 389–410.

Nuclear Regulatory Commission (formerly U.S. Atomic Energy Commission) (1972) Safety guides for water cooled nuclear power plants, Safety Guide 23: Onsite Meteorological Programs, pp. 23.1–23.6. USAEC, Division of Reactor Standards, Washington, DC 20545.

Pasquill F. (1961) The estimation of the dispersion of windborne material. *Met. Mag.* **90**, 33–49.

Pasquill F. (1976) Atmospheric dispersion parameters in Gaussian plume modeling. Part II. EPA-600/4-76-030b. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Pendergast M. M. and Crawford T. V. (1974) Actual standard deviations of vertical and horizontal wind direction compared to estimates from other measurements. In preprint volume of Symp. Atmospheric Diffusion and Air Pollution Am. Met. Soc., Santa Barbara, CA, pp. 1–6.

Slade D. H. (ed.) (1968) Meteorology and atomic energy 1968. U.S. Atomic Energy Commission, Oak Ridge, TN 37830.

Slade D. H. (1969) Wind measurements on a tall tower in rough and inhomogeneous terrain. *J. appl. Met.* **8**, 293–297.

Smith M. E. and Frankenberg T. T. (1975) Improvement of ambient sulfur dioxide concentrations by conversion from low to high stacks. *J. Air Pollut. Control Ass.* **25**, 595–601.

Smith R. A. (1859) On the air of towns. *Chem. Soc. London, Q. J.* **11**, 196–235.

The Research Corporation of New England (1975) Analysis of field experiment dispersion data to evaluate the split sigma versus the delta-T method of estimating horizontal and vertical diffusion rates. Wethersfield, CT. (Report prepared for Northeast Utilities Service Company).

Turner D. B. (1970) Workbook of atmospheric dispersion estimates. AP-26. U.S. Environmental Protection Agency, Research Triangle Park, NC, 27711.